Sustainability: Understanding Life Cycle Assessments for Insect Ingredients

Current knowledge on traditional and insect protein carbon emissions

The concept of sustainability is multi-faceted, including environmental, social, and financial components. In recent decades there has been a great interest in the environmental aspect of sustainability to preserve natural resources, such as land, water, and fossil fuels for future generations. A life cycle assessment (LCA) is one way to quantify the environmental impacts that result from the production and use of a particular product. As explained by Acaroglu (2018), there are five stages of a product's life cycle assessment, including:

1. material extraction
2. manufacturing
3. packaging and transport
4. use (of product)
5. end of life (disposal)

An assessment method that began in the 1960s, LCA methodology has since evolved with heavy focus in the 1990s, and renewed focus in the 21st century with the increase in awareness, and concern for, environmental welfare. This increased awareness led to an ISO regulation (14040: Environmental Management – Life cycle assessment), standardizing the methodology used for these assessments (Acaroglu, 2018; ISO, 2021).

The International Organization of Standardization (ISO) *is an independent, non-governmental worldwide federation of technical committees whose purpose is to standardize procedures and tools for an array of scientific challenges.*

Environmental Sustainability through Greenhouse Gas (GHG) Emissions

Sustainability research has typically centered around environmental impacts, specifically GHG emissions from burning fossil fuels for energy production. The United States is the second largest contributor (by country) of global greenhouse gas emissions at 25% (Capestany, 2021). As of 2019, total U.S. GHG emissions consisted of carbon dioxide (CO_2) at 80%, followed by methane (CH_4, 10%), nitrous oxide (N_2O, 7%), and fluorinated gases (3%) (EPA, 2021). The agriculture industry accounted for 10% of these emissions and is examined by the EPA in three main sectors (Fig. 1).

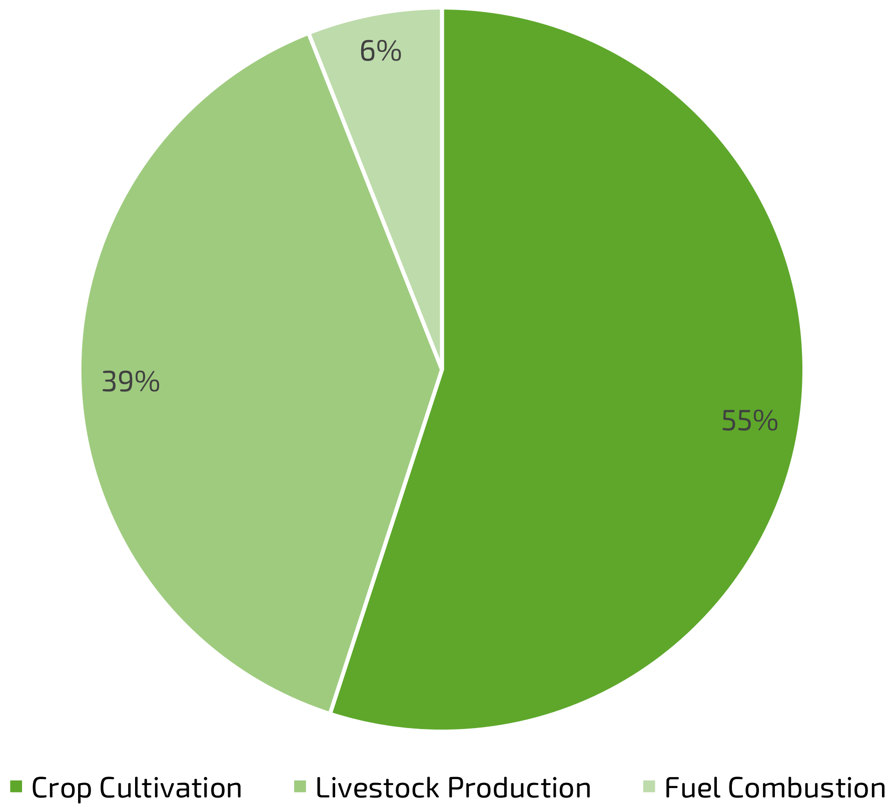

Figure 1. Percent contribution of agriculture industry sectors to total U.S. agriculture GHG emissions (EPA, 2021).

Additionally, up to 24% of the livestock contribution to GHGs is attributed to meat production processing (Skunca et al., 2015), derived primarily from poultry (32%), beef (11%), pork (10%), and sheep (5%) production (Capestany, 2021). As protein production grows to meet the demands of the growing human population, it is critical to consider not only optimization of existing systems, but also novel protein production systems that may complement or offset other environmental impacts. Overall U.S. GHG emissions are decreasing (down 13% in 2019 from 2005), indicating a trend toward sustainable models. And, while emissions within the agriculture industry* have continued to increase over time (Table 1), the net contribution per unit of agriculture production has declined. For example, from 2018 – 2019 total average U.S. red meat and poultry production increased by 2.71% (USDA, 2022), but U.S. GHG emissions from livestock production over this same time only increased by 0.7% (EPA, 2021).

Table 1. Agriculture industry* greenhouse gas emissions (MMT, CO_2-e) over time (EPA, 2021).

Emissions, CO_2-e	**1999**	**2009**	**2019**
Crop Cultivation	334.50	344.71	368.07
Livestock Production	236.67	243.67	260.54
Fuel Combustion	41.57	48.02	40.84
Total	612.74	636.18	669.46

Standard Measurements & Units

In addition to "GHG emissions" collectively referring to CO_2, CH_4, and N_2O emissions reported as CO_2-equivalents (CO_2-e), "carbon footprint" and "Global Warming Potential" (GWP) are alternative representative terms found throughout the literature (Dunkley et al., 2015). The CO_2-e is an effort to standardize GHG emission reporting by expressing N_2O and CH_4 in terms of an equivalent amount of CO_2 (Dunkley et al., 2015). Measures reported in the literature may be for total species production, species liveweight, carcass weight, or edible protein fraction (Capper & Cady, 2020; Dunkley et al., 2015; ISO, 2021). Units are typically reported as million metric tons (MMT) or kilograms (kg) per the chosen species measurement.

This review has focused on standardized measures and units from the literature, focusing on reported CO_2-e/kg edible protein fraction per animal species using a cradle-to-gate LCA approach in the United States within the last 12 years (2010 – current); a single study including global data (Poore & Nemecek, 2018) and a single study including data from the Organization for Economic Cooperation and Development (OECD), which includes values from the U.S. (DeVries & de Boer, 2010), were also chosen for inclusion. Edible protein was chosen as the functional unit of focus due to protein being the most expensive component of animal diets, and for the implications on manure management.

Greenhouse Gases (GHG): *collective reporting of CO_2, CH_4, and N_2O emissions as CO_2-e.*

CO_2-e: *weighted measurement of GHG emissions relative to the reference gas of CO_2.*

Carbon Footprint: *another collective term for reporting CO_2, CH_4, and N_2O emissions.*

Global Warming Potential (GWP): *ratio of accumulated radiative emission of 1 kg of CO_2, CH_4,*

Livestock Species Edible Protein and GHGs

Livestock species were narrowed to include poultry (egg and chicken protein fractions), swine (pork protein), and beef cattle (beef protein). The literature reports a wide range of CO_2-e values associated with the production of these protein fractions (Fig. 2). From these values, the following means (kg CO_2-e/kg edible protein) were calculated: 37.8 for egg, 8.9 for chicken, 23.9 for pork, and 61.3 for beef. Dietary ingredients and feeding practices also contribute to the variation in CO_2-e values within species. For example, Pelletier et al. (2013) report the largest portion of emissions in layer and egg production come from total feed inputs at 82%. This is in comparison to layer manure emissions at 6.8%. Taking a further look at feed inputs as the largest source of emissions for poultry production, raw materials account for 72%, followed by processing (16%) and transportation (12%). Animal-derived ingredients contribute greater CO_2-e emissions than plant-derived ingredients, indicating that reduction and/or replacement of these feed inputs should be considered if nutritionally equivalent alternatives exist (Pelletier et al., 2013). Similarly, the range of beef emission values (27 – 84 kg CO_2-e/kg edible protein) can be highly attributed to the feeding model employed including historical diet models versus current industry diets (Baber et al., 2018). It is no surprise that improvements in diet have been recommended as one of the most efficient ways to reduce GHG emissions for livestock production (Pelletier et al., 2013; Phetteplace et al., 2001).

Insect Species Edible Protein and GHGs

With the increasing awareness of, and concern for, environmental sustainability it is no surprise that insect products are garnering attention from the livestock production industry. Insect products are highly sustainable, requiring only a fraction of fossil fuels as traditional livestock species (Capestany, 2021), evidenced by the lower mean CO_2-e value of insect edible protein fractions (7.3 kg CO_2-e/kg edible protein) compared to livestock species edible protein fractions (Fig. 2). Also demonstrated in Figure 2 is the impact of feed inputs on insect production CO_2-e values. The highest reported emission value for BSFL of 19 kg CO_2-e/kg of edible protein is the result of feeding larvae human-grade foods while the lowest emission value in the same publication of 3.0 is the result of feeding larvae food by-products (Bosch et al., 2019). This is most likely due to the additional processing and handling associated with human-grade foods.

The effects of feed inputs on BSFL performance support the use of food by-products (Oonincx et al., 2015) which also support the aim of mitigating landfill additions and a circular economy.

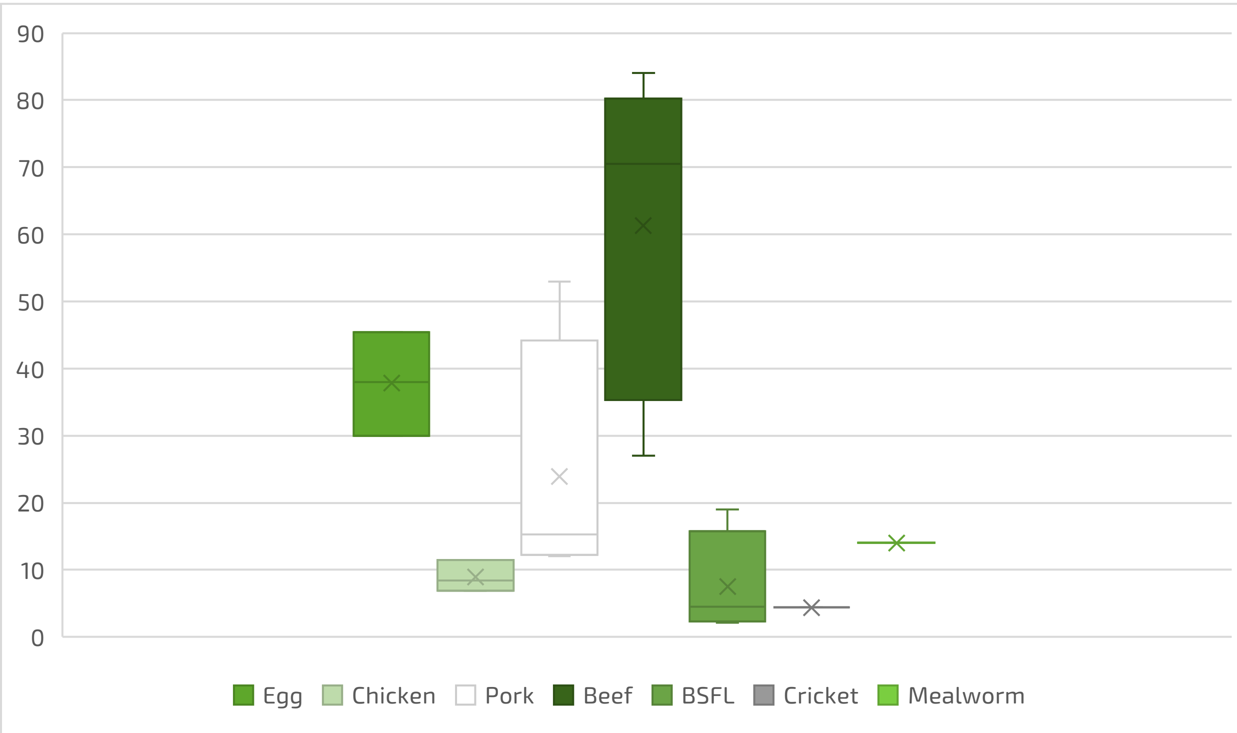

Figure 2. Carbon footprints (kg CO_2-e/kg edible protein) reported in the literature for livestock production in the U.S. and global insect production (Asem-Hiablie et al., 2019; Baber et al., 2018; Bosch et al., 2019; DeVries & de Boer, 2010; Dunkley & Dunkley, 2013; Pelletier et al., 2013; Halloran et al., 2017; Poore & Nemecek, 2018; Salomone et al., 2017; Sanders & Webber, 2014;

Further Considerations

GHG values allow for standardized measures and reports of carbon footprints; however, there are additional factors that should be considered when employing GHG values in decision-making. For example, Koutsos et al. (2019) provide a detailed summary of the productive yield potential of plant, animal, and insect protein sources which reveals the incredible potential protein yield of BSFL at 114 kg/m^2 per year compared to chicken at 21.6 kg/m^2 per year. Although the average GHG output reported here for chicken (8.9 kg CO_2-e/kg edible protein) and BSFL (7.3 kg CO_2-e/kg edible protein) may not appear drastically different at first glance, considering the potential yields, GHG values, and edible protein contents (chicken, 7.3% and BSFL, 17.5%; Koutsos et al., 2019), it would require 12.6 m^2 of chicken production to equal the edible protein produced by BSFL in just one square meter. Producing an equal amount of chicken edible protein results in a 17.8% increase in GHG output over that of BSFL. These results demonstrate the potential to reduce GHG emissions and simultaneously reduce land use through the production and processing of insect ingredients for use in animal feed and pet foods.

Conclusion

It is important to note that this information is derived from a selection of papers representing current knowledge. There are many potential sources of CO_2-e and different ways to empirically examine sustainability within the agriculture industry. There are also additional protein ingredients used in animal feed and pet foods that were not considered in this summary, such as plant (soybean meal) and synthetic (methionine) protein sources. As a key component of the novel insect production industry, EnviroFlight looks forward to exploring insect production alongside sustainability management and reporting to provide meaningful information to the agriculture industry regarding the complements between traditional and novel feed ingredients.

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